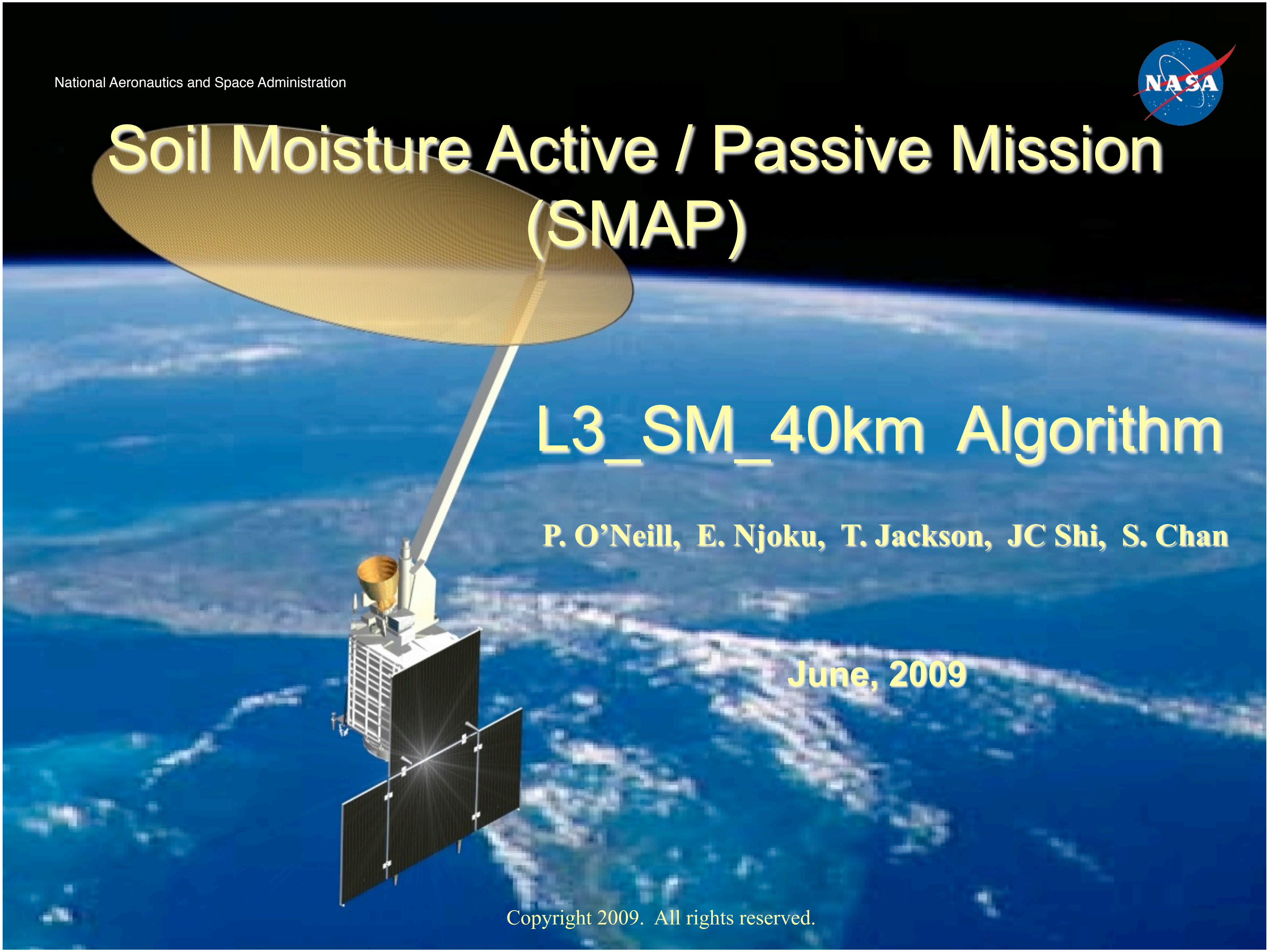


National Aeronautics and Space Administration

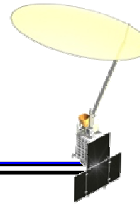
Soil Moisture Active / Passive Mission (SMAP)

L3_SM_40km Algorithm

P. O'Neill, E. Njoku, T. Jackson, JC Shi, S. Chan

June, 2009

Microwave Emission Model for L3_SM



Surface Brightness Temperature:

$$T_{Bp} = T_s\,(1 - r_p)\,\exp(-\tau_c) + T_c\,(1 - \omega)\,[1 - \exp(-\tau_c)]\,[1 + r_p \exp(-\tau_c)]$$

where

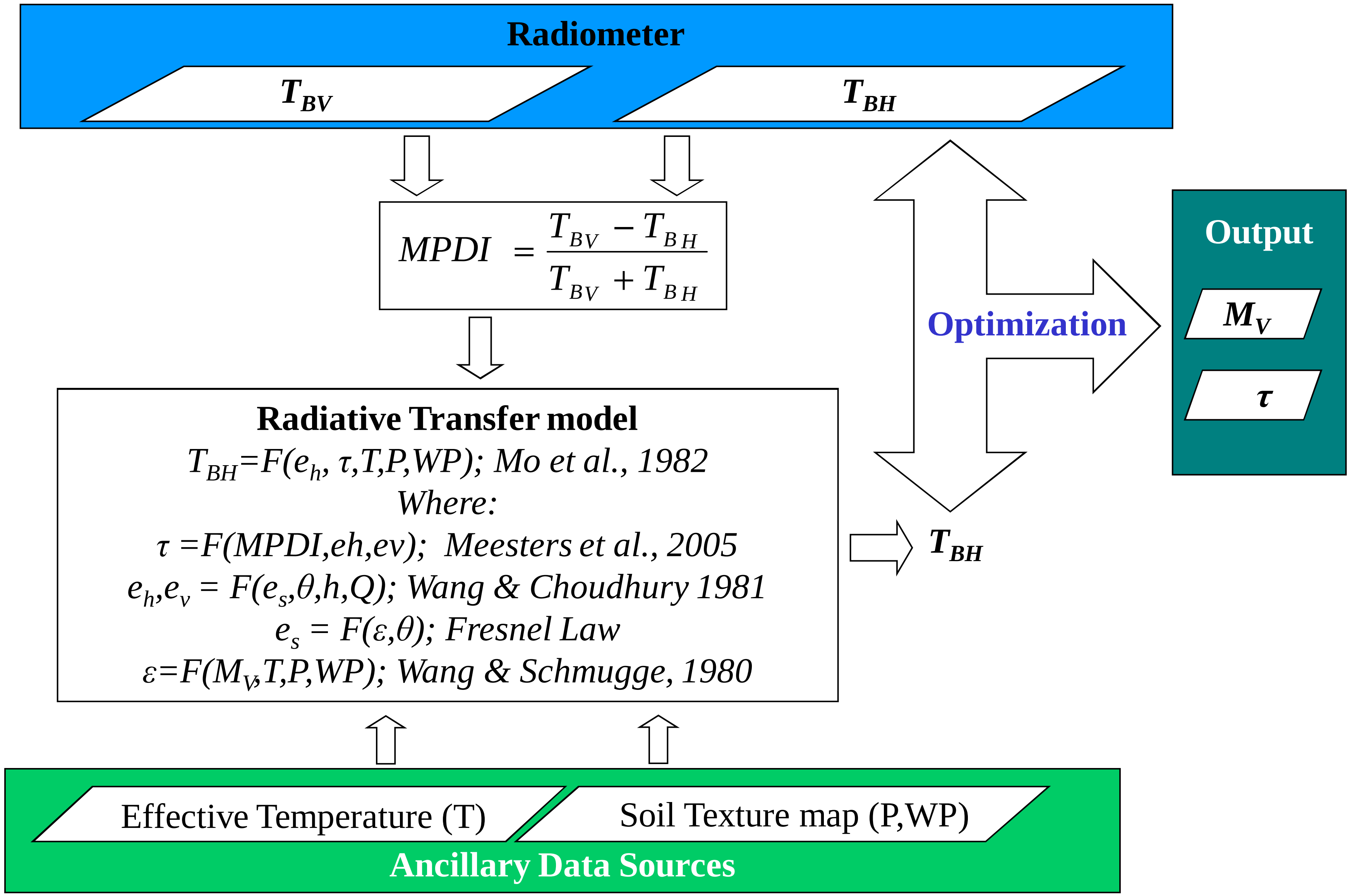
- T_s and T_c are physical temperatures of the soil and vegetation canopy (K)
- r_p is the soil reflectivity [related to the emissivity by $e_p = (1 - r_p)$]
- τ_c is the vegetation opacity along the slant path where $\tau_c = b\, W_c \sec\theta$
  [W_c is the vegetation water content (kg/m^2) and b is a vegetation parameter]
- ω is the vegetation single scattering albedo
- soil roughness can be corrected as $r_{p\ smooth} = r_{p\ rough} / \exp(-h)$
- $r_{p\ smooth}$ is then related to the soil dielectric constant ε by the Fresnel equations
- soil moisture content m_v (% volumetric) is then estimated from the dielectric constant using dielectric models

note: if the air, vegetation, and near surface soil can be assumed to be in thermal equilibrium, then $T_c \approx T_s = T_{eff}$, the effective temperature over the microwave sampling depth

L3_SM_40km Algorithms

- **Several radiometer retrieval approaches based on the tau-omega model have been evaluated to date, with varying requirements for ancillary data:**
  - **Single-Channel (SCA): uses H-pol brightness temperature which is corrected sequentially for surface temperature, vegetation water content, and surface roughness using ancillary data**
  - **Iterative (2CA): adjusts soil moisture and vegetation water content iteratively to minimize the difference between computed and observed T_{BV} and T_{BH}; both SM and another parameter (such as VWC) can be retrieved**
  - **Land Parameter Retrieval Model (LPRM): 2-channel iterative approach which uses a microwave polarization difference index and emissivity to parameterize τ_c ; assumes τ_c and ω are the same for H and V polarization; assumes a constant ω**
  - **Reflectivity Ratio (RR): uses both T_{BV} and T_{BH} and vegetation & roughness correction factors for SM retrieval; algorithm now proposes to use SMAP radar data to determine vegetation correction factor needed in the passive retrieval**

LPRM: Land Parameter Retrieval Model



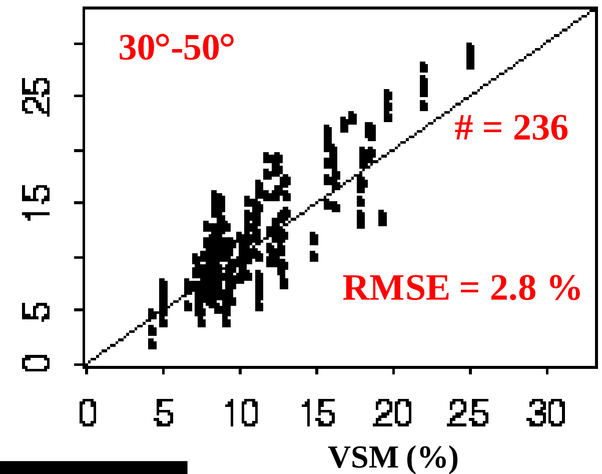
Reflectivity Ratio

Bare Surface Algorithm

Technical Concept of the algorithm:

Weighted polarization measurements to minimize the roughness effects

Validation from 4 year's ground experiment data (BARC'79-82)



Algorithm (Shi et al., 2002, IEEE/TGRS):

$$Log(r_v/r_h) = a(\theta)+b(\theta)\cdot\log(R_v)+c(\theta)\cdot\log(R_h)+d(\theta)\cdot R_v/R_h$$

Where R_v and R_h are effective reflectivity. The coefficients *a, b, c,* and *d* are determined by IEM simulated database.

Vegetated Surface Algorithm

1) **Radar measurement to estimate Vc (Shi et al., 2003, 2005 IGARSS)**

- **Using polarization synthesizing technique from radiometer measurement (V,H) to estimate soil moisture**

Reflectivity Ratio (2)

$$\frac{r_v^{'}}{r_h^{'}} = \exp\left[a + b\cdot\log(R_v^e\cdot V_e) + c\cdot\log(R_h^e\cdot V_e) + d\cdot R_v^e / R_h^e\right]$$

(1) $f1$(soil moisture,vegetation)

$$\frac{R_v^e}{R_h^e} = \frac{r_v^{'}}{r_h^{'}}\frac{H_v^{'}}{H_h^{'}}$$

(2) $f2$(soil moisture,roughness)

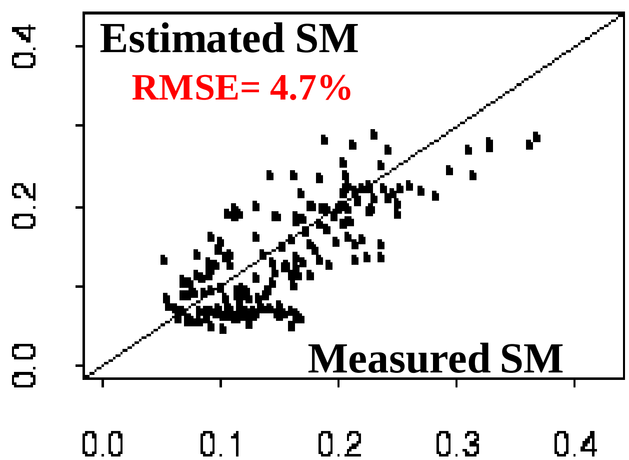
Convert rv/rh to soil moisture

$$\frac{H_v^{'}}{H_h^{e'}} = f + g*\frac{H_v^{'}}{H_h^{'}} + h*\frac{R_v^e}{R_h^e}$$

(3) $f3$(roughness relation)

$$\min(error) = \frac{R_v^e\cdot V_e}{(R_h^e\cdot V_e)^e} = \frac{H_v^{'}}{H_h^{e'}}\cdot V_e^{'1-e}$$

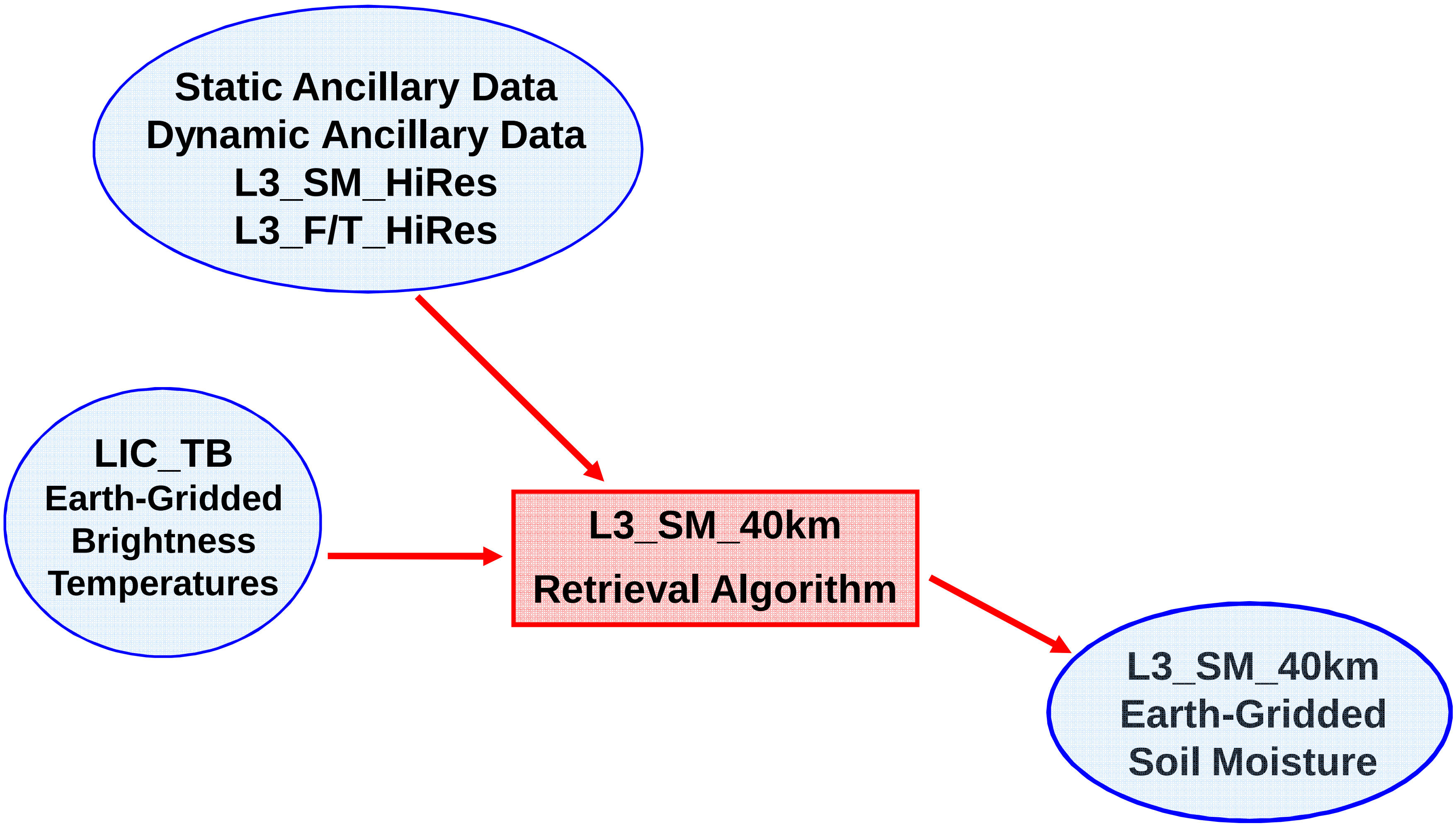
(4) $f4$(vegetation,roughness)



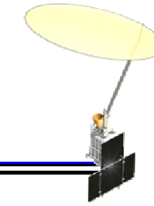
Summary

1. Radar measurement can provide Vc – no assumption of small albedo is necessary in representing radiometer measurements
2. Using polarization synthesizing technique from radiometer measurement (V,H) to estimate soil moisture
3. Testing with SGP'99 and SMEX'02 PALS measurements are encouraging

Radiometer SM L3 Data Flow



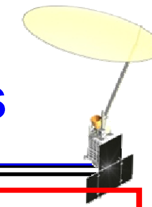
L3_SM_40km Inputs / Outputs



DATA INPUT:	
Grid cell location on fixed Earth grid (lat, lon)	
Time tag (date and time of day)	
Calibrated L1C_TB	
Static ancillary data [permanent masks (land / water, urban, etc.), soil type, DEM info, % land cover types]	
Dynamic ancillary data :	
-- Soil temperature	
-- Vegetation water content	
-- Vegetation parameters (*b*, *τ*, *ω*)	
% open water in pixel -- temperature of open water from Ts at 6 am	**[from L3_SM_HiRes]**
Frozen ground flag	**[from L3_F/T_HiRes]**
Precipitation flag (if set)	**[from ????]**
Snow/ice flag (if set)	**[from ????]**
RFI flag	**[from L1_TB]**
Quality flag	**[from L1_TB]**

DATA OUTPUT:
Grid cell location on fixed Earth grid (lat, lon)
Time tag (date and time of day)
Calibrated L1C_TB
Retrieved soil moisture for 6 am overpass
Dynamic ancillary data :
-- Soil temperature
-- Vegetation water content
-- Vegetation parameters (*b*, *τ*, *ω*)
% open water in pixel -- temperature of open water
Frozen ground flag
Precipitation flag (if set)
Snow/ice flag (if set)
RFI flag
Quality flag

Potential Ancillary Data Sources for SMAP L3 Products



PARAMETER	SOURCE	FREQUENCY
Surface Classification (incl. land/water mask)	NGA/SRTM, NGDC, GED v.2, JERS, PALSAR	land/water mask done once (updated if necessary)
Land Cover (Classification and VCF)	VIIRS; MODIS data sets	seasonally
Soil Texture	STATSGO & equiv. in US and Europe World soils map – Reynolds data bank	done once
Roughness (large area topography)	DEM (SRTM, USGS)	done once
Roughness (local microroughness)	Historical data base and/or SMAP radar	seasonally
Vegetation (*b, W, τ, ω*)	VIIRS products MODIS / historical phenology	updated every 1-2 weeks
Surface air temperature (freeze/thaw)	WMO, SOGS	updated daily at overpass time
Effective Soil Temperature (soil moisture)	ECMWF forecast model NCEP forecast model GMAO model MW / VISIR LSTs as available	updated daily at overpass time
Reference initial freeze/thaw states	JERS, PALSAR	done once
RFI flag	SMAP; Aquarius / SMOS data base	done for each T_B
Other flags: Transient flooding	SMAP radar	(only some flags may be set within SMAP)
Rain / precipitation	GPM or GCOM-W or forecast model	
Snow / ice	SSMI or GCOM-W or forecast model	
Frozen ground	SMAP radar or SSMI or GCOM-W or forecast model	

L3_SM Single-Channel Error Budget Table

Error Source	Est. TB Error (K)
Atmospheric Gases & Clouds	**0.15**
Soil Temperature (2°C error)	**1.7**
Vegetation Water Content (10%)	**1.6**
Model Parameterization (h, ω, b, all at 5% error, classification, etc.)	**1.4**
Surface Heterogeneity	**0.9**
Total RSS of Geophysical Errors	**2.87**
Radiometer Precision & Calibration Stability	**1.3**
Total RSS Error	**3.15**

[Error budget to be confirmed]

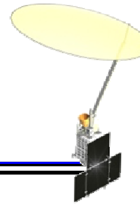
[radiometer absolute calibration error not yet included]

SM Algorithm Tasks

- help to generate master static ancillary data file based on Earth grid chosen
- need careful sensitivity studies showing error differences between algorithms
  -- generate equivalent error budget tables based on other algorithms
- additional work on vegetation parameterization (ex. Ray Hunt's work w/ VISIR -- corn VWC $R^2 \approx .78\text{-}.89$, RMSE $\approx$ 0.46-49 kg/m^{2}; use w/ allometric eqs. to get woody veg.)
- additional work on scaling and vegetation aggregation (effective VWC)
- consideration of pixel heterogeneity caused by manmade structures such as buildings, roads, etc.
  -- what is the emissivity of manmade structures?
- use of SMOS / Aquarius data to test algorithms
- field campaigns like SMAPVEX08 can examine specific algorithm issues
- algorithm testbed can be used for trade studies and OSSEs

Twin Otter w/PALS and ComRAD microwave truck system, SMAPVEX08, October 13, 2008

Parameter Look-Up Table



Class	Category Name	s (cm)	h	ω	b	b_v	b_h	f_T
1	Crop/mixed farming	1.5	0.15	0.05	0.13	0.143	0.117	0.2
2	Short grass	1.0	0.10	0.05	0.20	0.22	0.18	0.0
3	Evergreen needleleaf tree	1.0	0.10	0.12	0.20	0.23	0.17	0.8
4	Deciduous needleleaf tree	1.0	0.10	0.12	0.20	0.23	0.17	0.8
5	Deciduous broadleaf tree	1.0	0.10	0.12	0.20	0.23	0.17	0.8
6	Evergreen broadleaf tree	1.0	0.10	0.12	0.20	0.23	0.17	0.8
7	Tall grass	1.0	0.10	0.05	0.20	0.22	0.18	0.0
8	Desert	1.0	0.10	0.00	0.00	0.00	0.00	0.0
9	Tundra	1.0	0.10	0.05	0.20	0.22	0.18	0.0
10	Irrigated crop	1.5	0.15	0.05	0.13	0.143	0.117	0.0
11	Semidesert	1.0	0.10	0.05	0.10	0.11	0.09	0.0
12	Bog or marsh	1.0	0.10	0.05	0.10	0.11	0.09	0.0
13	Inland water	0.1	0.01	0.00	0.00	0.00	0.00	0.0
14	Evergreen shrub	1.0	0.10	0.12	0.20	0.22	0.18	0.0
15	Deciduous shrub	1.0	0.10	0.12	0.20	0.22	0.18	0.0
16	Mixed woodland	1.0	0.10	0.12	0.20	0.23	0.17	0.8
17	Short grass/crop	1.2	0.12	0.05	0.17	0.187	0.153	0.1
18	Tall grass/crop	1.2	0.12	0.05	0.17	0.187	0.153	0.1
19	Crop/mixed woodland	1.2	0.12	0.08	0.17	0.191	0.149	0.5
20	Crop/evergreen needleleaf tree	1.2	0.12	0.08	0.17	0.191	0.149	0.5
21	Crop/deciduous broadleaf tree	1.2	0.12	0.08	0.17	0.191	0.149	0.5
22	Irrigated crop/deciduous broadleaf tree	1.2	0.12	0.08	0.17	0.191	0.149	0.5
23	Short grass/mixed woodland	1.0	0.10	0.08	0.20	0.225	0.175	0.4
24	Evergreen needleleaf/short grass	1.0	0.10	0.08	0.20	0.225	0.175	0.4
25	Evergreen needleleaf/ evergreen broadleaf	1.0	0.10	0.12	0.20	0.23	0.17	0.8

-- will SMAP use the same approach?

-- how do we design field measurements or analyses to refine these numbers?

-- do the numbers vary seasonally?

-- how do the b parameters vary with polarization?

[from Hydros OSSE]

Pre- and Post-Launch Test & Evaluation

Pre-Launch – leads to selection of baseline algorithm

- **refine model parameterizations (incl. polarization & seasonal dependence)**
- **develop & compare algorithm error budgets**
  - **-- error in ancillary data**
- **evaluate algorithm performance using:**
  - **-- algorithm testbed simulations**
  - **-- analysis of ground & A/C measurements**
  - **-- SMOS brightness temperatures & other SMOS products**

Post-Launch – are accuracy requirements met?

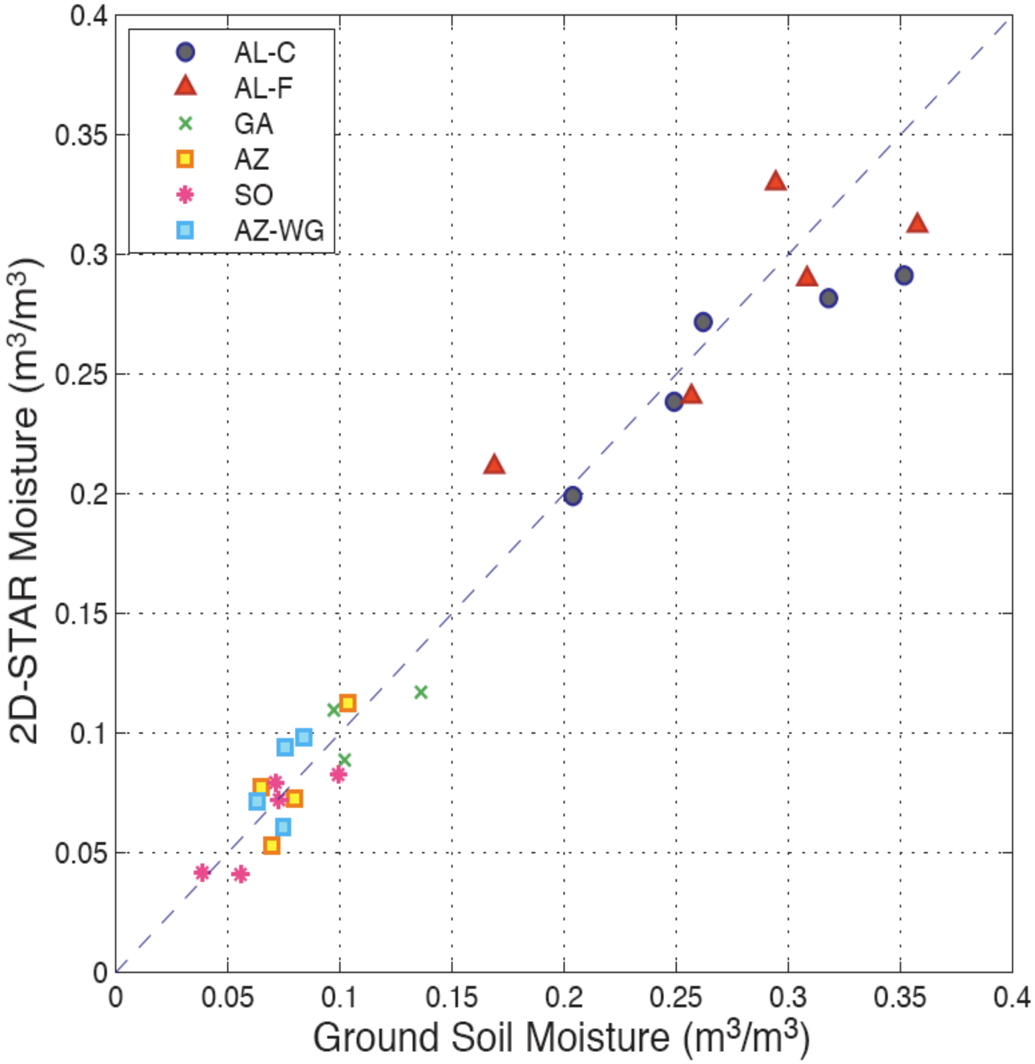
- **comparison against long-term measurement networks**
- **field measurements from intensive SMAP C/V field campaigns**
- **modeling / data assimilation & other satellites (GCOM-W?)**

BACKUP


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
SMAP
Soil Moisture Active-Passive
CARBON CYCLE
WATER CYCLE
ENERGY CYCLE
SOIL MOISTURE • FREEZE/THAW

2D-STAR Soil Moisture vs. Ground Measurements

SITE-SPECIFIC CALIBRATION



Summary of Results

Site	RMSE (m^3/m^3)	Corr
Alabama	0.033	0.89
Georgia	0.013	0.62
Arizona	0.012	0.85
Sonora	0.011	0.88
Total	0.022	0.98

b and h optimized using ground measurements of soil moisture from SMEX04 field campaign

Parameterization Issue

[From Dongryeol Ryu, U. Melbourne]

2D-STAR Soil Moisture vs. Ground Measurements

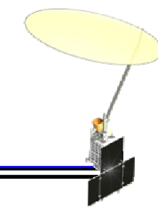
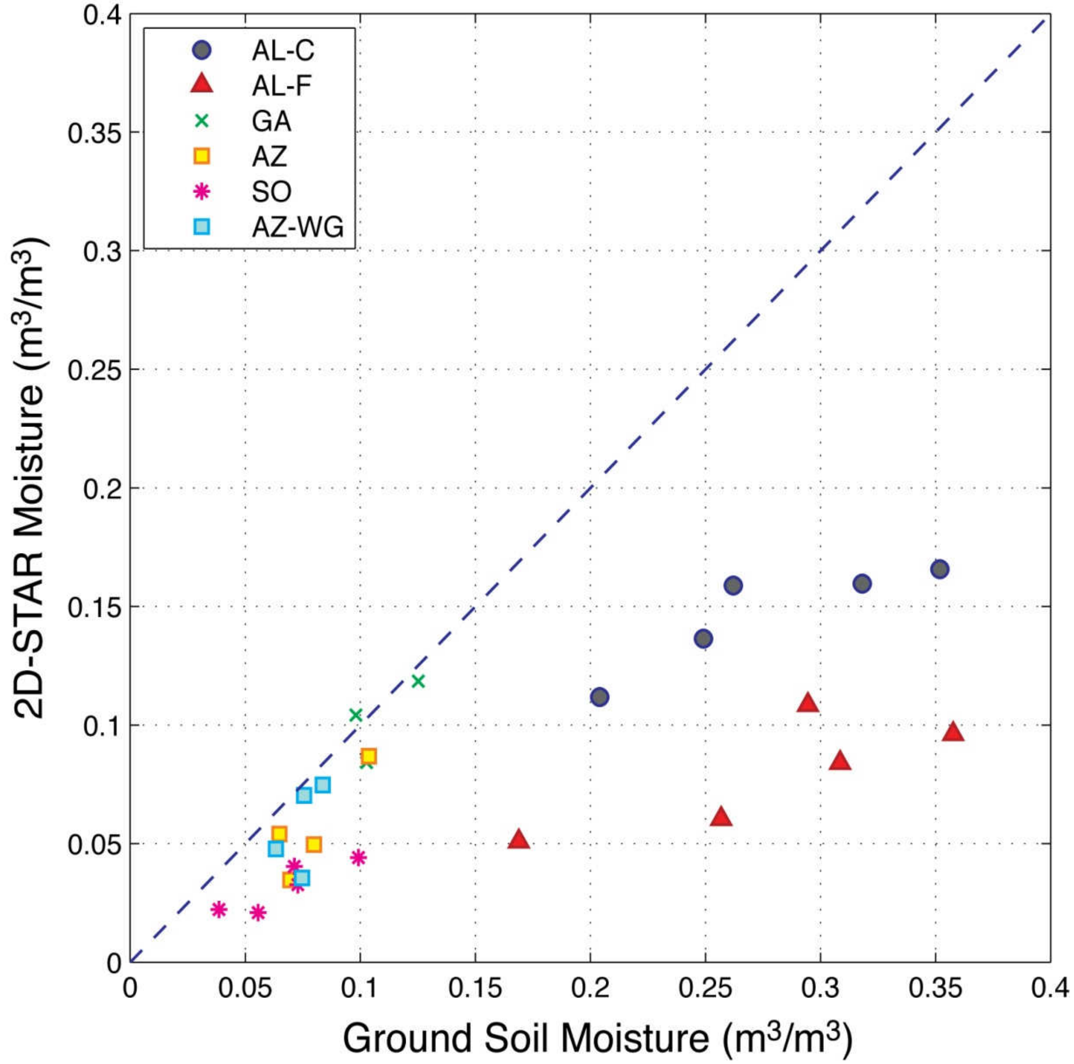


TABLE LOOK-UP PARAMETERS



Summary of Results

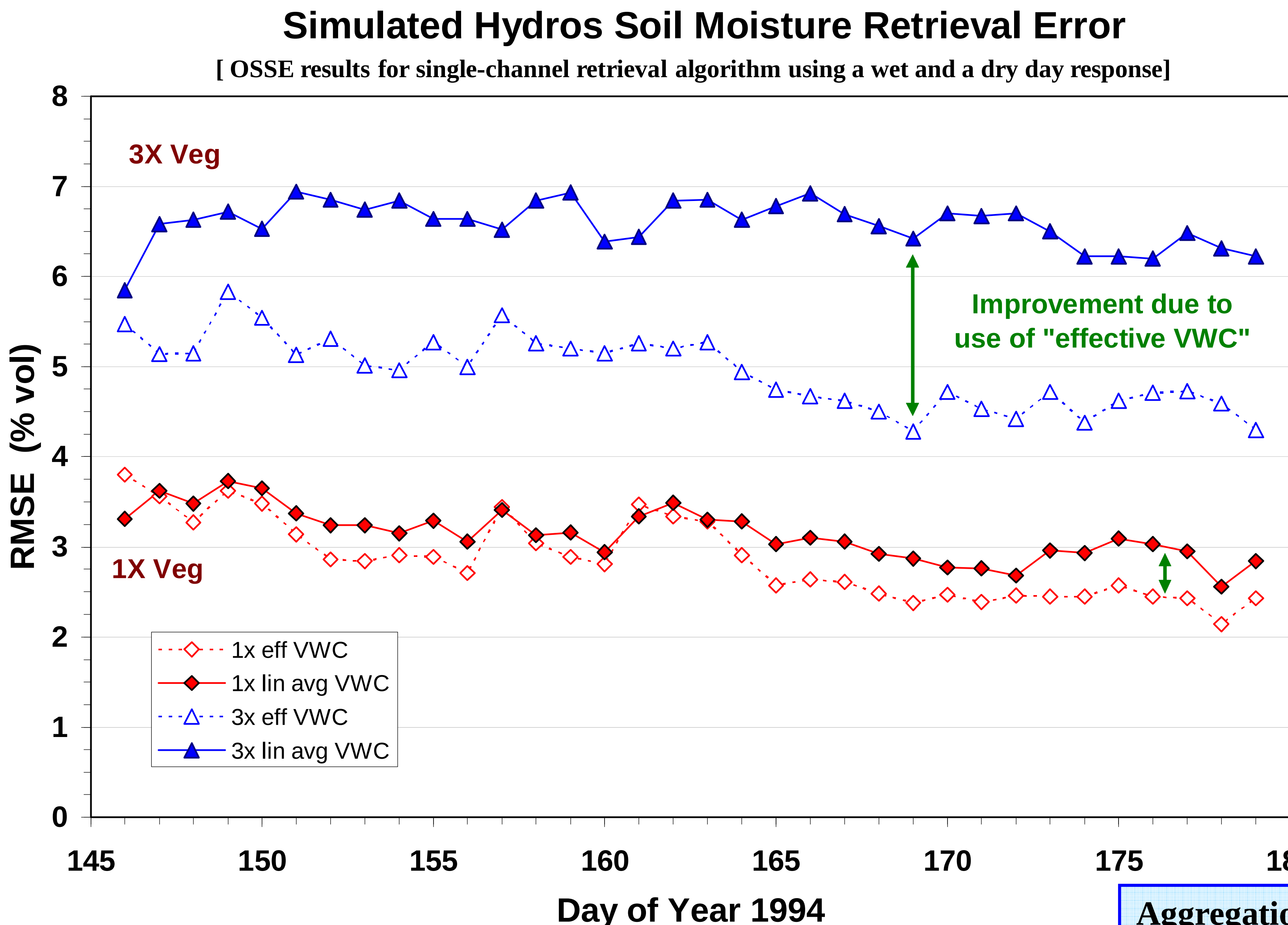
Site	RMSE (m^3/m^3)	Corr
Alabama	0.172	0.44
Georgia	0.015	0.61
Arizona	0.023	0.74
Sonora	0.038	0.89
TOTAL	0.088	0.91

b and h obtained from look-up table from Hydros OSSE paper and VWC from non-optimum VISIR equation

Parameterization Issue

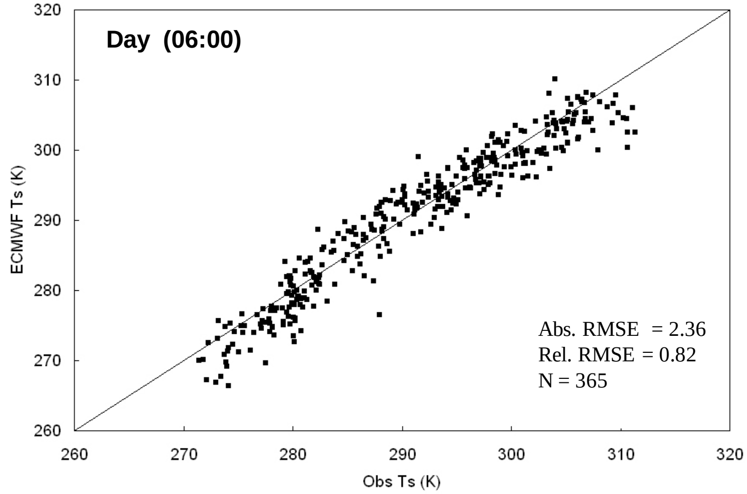
[From Dongryeol Ryu, U. Melbourne]

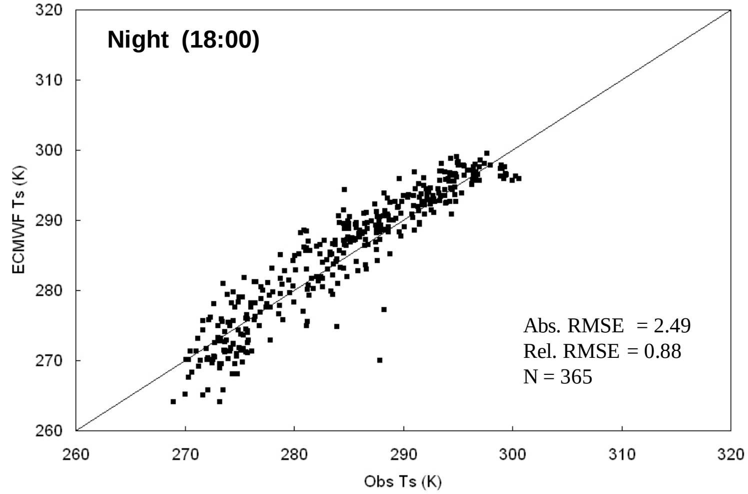
Effective VWC Correction

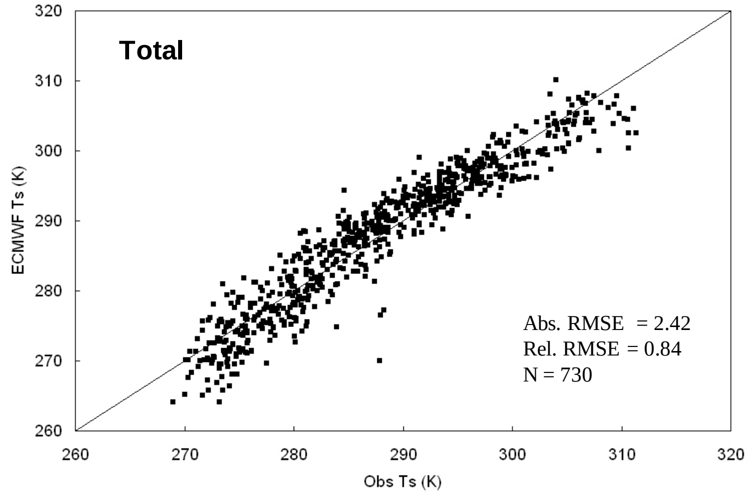


Aggregation Issue

ECMWF T_s vs Mesonet T_s : SMAP overpass time

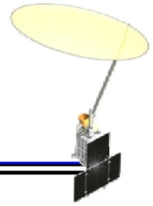






T_S Accuracy Issue

ECMWF forecast surface temperatures and Oklahoma MESONET (2 mm) surface temperatures at the SMAP overpass times of 06:00 (day) and 18:00 (night) hours local time for 2003.



Radar Transient Water Detection

- ***Permanent*** **water bodies can be identified using MODIS and SRTM data before launch**

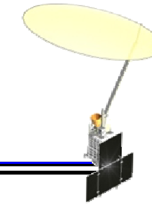
- ***Transient*** **water bodies can be identified using time series radar data**
  - **for bare surfaces, the total backscattering cross section (HH+VV+HV) will be decreased significantly for standing water if the wind speed is not very high**

    -- more work is needed for this algorithm to determine the threshold value

  - **for vegetated surfaces, the co-polarization ratio (HH/VV) will increase significantly with standing water due to the double bounce component**

    -- more work is needed for this algorithm to determine the threshold value

LPRM: Land Parameter Retrieval Model



- LPRM (Owe et al., 2001), is designed to retrieve soil moisture from dual polarization brightness temperatures without a-priori information about the vegetation.
- LPRM is a combination of modules to describe the radiative transfer of microwave emission from soil and vegetation.
- A special characteristic of LPRM is the internal analytical approach to solve for vegetation optical depth (Meesters et al., 2005).
- The only ancillary input needed for LPRM is the effective temperature for L-band, and a static soil texture map.
- LPRM has been applied to various satellites and frequencies to create a 30+ year record of global soil moisture (Owe et al., 2008), including AMSR-E (C,X), TRMM (X), and SMMR (C).
- Parameterization of LPRM for L-band airborne data (de Jeu et al. 2009).

LPRM: Validation

Validation studies with in situ soil moisture data

Forested Regions: The Netherlands, Germany[1]
Agricultural regions: USA, Russia, Luxembourg, Germany, France [1,2,3,4,7]
Semi Arid Regions: Spain, Turkmenistan, Mongolia, Australia [2,5,6]

Evaluation with other RS and modeled soil moisture products[1,4,5,6,7,8,9,10,11]

Research Applications: Climate research[12,13], Numerical Weather Prediction[10], Runoff prediction[14]

[1]Rebel et al., in prep; [2]Owe et al., *JGR* 2008;
[3]De Jeu and Owe, *IJRS* 2003;[4]Weerts et al., *CAHMDA* 2008;
[5]Draper et al., *RSE* 2009; [6]Wagner et al., *HG* 2007;
[7]Rudiger et al., *JHM* 2009 ; [8]De Jeu et al *SurvGeophys* 2008,
[9]Scipal et al., *GRL* 2008, [10] Schuman et al., HESS 2009, [11]Mladenova et al., IEEE 2009
[12]Liu et al., GRL 2007, [13]Liu et al, WRR 2009, [14]Beck et al., submitted

LPRM: References

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